SEM contrast of semiconducting and semi-insulating samples

H.-J. Fitting[1] and J. Z. Kovacs[2]

1.University of Rostock, Inst. of Physics, Universitaetsplatz 3, D-18051 Rostock, Germany
2. Hamburg University of Technology, Institute for Optical and Electronic Materials,
Eissendorfer Str. 38, D-21073 Hamburg, Germany

hans-joachim.fitting@uni-rostock.de

Keywords: Non-conductive samples, Low energy SEM, Potential contrast, Resistance model.

The invention of the scanning electron microscopy (SEM) is concerned with Max Knoll in Berlin 1935 published in [1]. Even in this first paper charging phenomena of insulating samples are described too. In recent years the electron beam irradiation and charge injection in insulating samples have been described by means of an electron-hole flight-drift model (FDM) implemented by a computer simulation [2-4]. For bulk full insulating samples the time dependent secondary electron emission rate $\sigma(t)$ and surface potential $V_0(t)$ approach the final stationary state under the condition $j(x,t)$ = const = 0 and $\sigma = 1$. But in semiconducting and semi-insulating samples these relations are not fulfilled. In this context we want to remember to an old resistance model, e.g. quoted in [5]. There a certain sample resistance R_i controls a partial charging of the semiconducting or semi-insulating sample as demonstrated in **Fig.1**. The actual landing energy $E_v = eU_v$ of the electron beam is enhanced or diminished by the surface potential $U_s \gtrless 0$:

$$E_v = e_0U_v = e_0(U_0 + U_s) = E_0 + e_0 (\sigma - 1)\, i_0\, R_i \qquad (1)$$

The interceptions of the resistance lines $\sigma(U_0, U_vR_i)$ with the SE yield curve $\sigma(E_v{=}E_0)$ result in the actual state of charging (U_s) and SE yield $\sigma(E_v)$. So we see that the (σ_0=1)–energies E_0^{I} and E_0^{II} are for the first value labile and for the second one stable (even attractive) as mostly used in simple charging models for full insulating samples $R_i = \infty$. Hence for conducting samples $R_i = 0$ we get no charging and $E_v = E_0$.

In **Fig.2** a potential contrast around the first (σ=1)-point $E_0 \lessgtr E_0^{I}$ (see **Fig.1**) is demonstrated. The metal (Cu) islands appear darker than the silicon substrate for very low electron beam energies E_0=10 eV$<E_0^{I}$ with a contrast inversion at $E_0 \cong 50$ eV $\cong E_0^{I}$ and an element contrast up to 5 keV, see [6]. Responsible is the SE emission σ in dependence on the insulating SiO_2 oxide layer on the semiconducting Si substrate as demonstrated in **Fig.3**. The data of pure Si are taken from Ref. [5]; the Monte Carlo results for pure silica SiO_2 from Ref. [7]. In **Fig.4** a contrast inversion appears from the initial uncharged state (pure element contrast) to the charged-up insulating epoxy resin matrix with imbedded carbon nanotubes (CNT), [8].

References

[1] M. Knoll, Zeitschrift f. Technische Physik **11** (1935) p467.
[2] X. Meyza, D. Goeuriot, C. Guerret-Piécourt, Tréheux, H.-J. Fitting, JAP **8** (2003) p5384.
[3] M. Touzin, D. Goeuriot, C. Guerret-Piécourt, et al., JAP **99** (2006) p114110.
[4] N. Cornet, D. Goeuriot, C. Guerret-Piécourt, et al., JAP **103** (2008) p064110.
[5] I. M. Bronshtein, B. S. Fraiman, "Secondary Electron Emission", Naúka, Moscow 1969.
[6] I. Muellerova, L. Frank, Adv. Imaging Electron Phys. **128** (2003) p309.
[7] E. Schreiber, H.-J. Fitting, J. Electron Spectroscopy & Rel. Phenomena **124** (2002) p25.
[8] J. Z. Kovacs, K. Andresen, J. R. Pauls, C. P. Garcia, et al., Carbon **45** (2007) p1279.

G. Kothleitner, M. Leisch (Eds.): MC2009, Vol. 1: Instrumentation and Methodology,
DOI: 10.3217/978-3-85125-062-6-081, © Verlag der TU Graz 2009

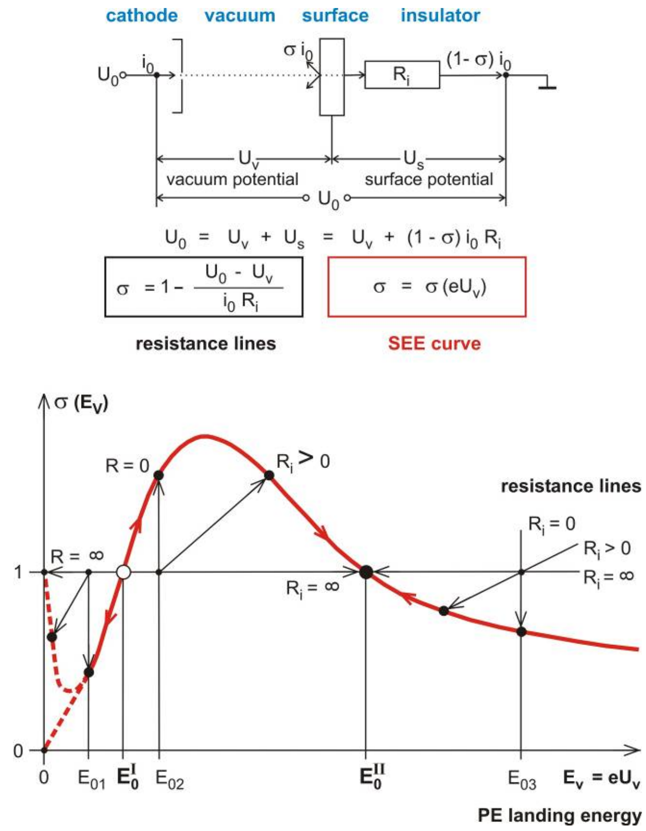

Figure 1. SEE resistance model for semiconductors and insulators; R_i internal sample resistance.

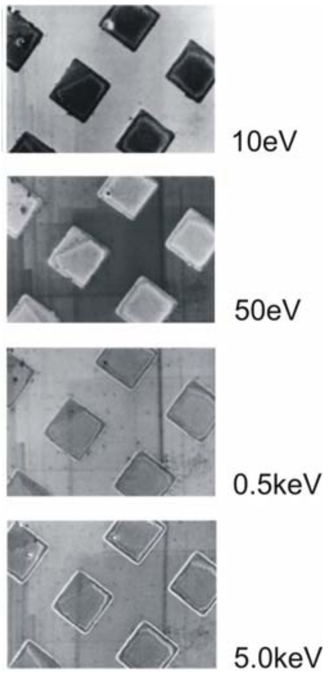

Figure 2. Potential contrast inversion of Cu islands on Si substrate at very low beam energies $E_0 \lesssim E_0^I$: with courtesy of I.Muellerova (ISI Brno) [6].

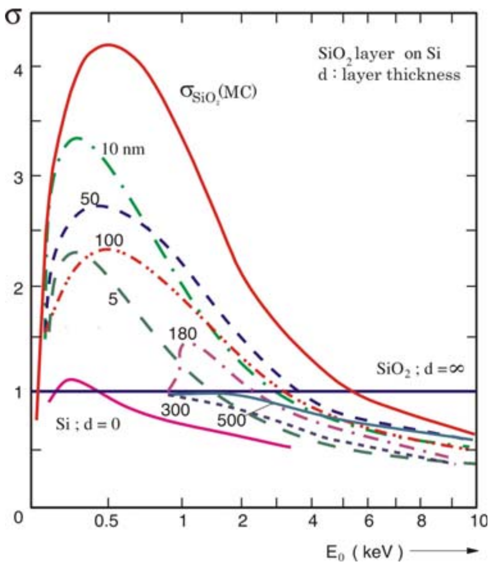

Figure 3. SE emission rate $\sigma(E_0)$ in dependence on the SiO_2 layer thickness d on Si substrate; pure Si (d=0) taken from [5], for pure (d=∞) silica obtained by Monte Carlo simulations of Ref. [7].

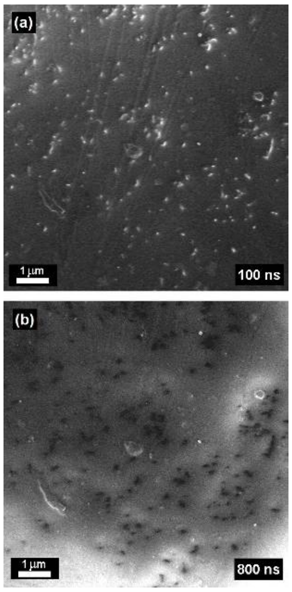

Figure 4. Time-dependent charge contrast inversion from short (100 ns above) to longer irradiation times t=800 ns (below) of carbon nanotubes CNT in epoxy resin [8]; $E_0 = 0.6$ keV.